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P.O. Box 1450
Alexandria, VA 22313-1450

VERIFICATION OF TRANSLATION

Dear Sir:

The undersigned hereby certifies that I am conversant in both Japanese and English languages, that I have prepared the attached English translation of Japanese text attached as Exhibit A, and that the English translation is a true, faithful and accurate translation of the attached Exhibit A.

I further declare that all statements made of my own knowledge are true and that all statements made on information and belief are with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under 18 USC § 1001, and that such false statements may jeopardize the validity of the application or any patent issuing therefrom.

Date: July 20, 2005

Signature: Masanori Fujimaki

Typed Name Masanori FUJIMAKI

Address: 39-12, Sin-Sakuragaoka 1-chome, Hodogaya-ku, Yokohama, Japan

AYES SOLOWAY P.C.
0 W. CUSHING STREET
TUCSON, AZ 85701
TEL. 520.882.7623
FAX. 520.882.7643

175 CANAL STREET
NCHESTER, NH 03101
TEL. 603.668.1400
FAX. 603.668.8567

[TITLE OF DOCUMENT] SPECIFICATION

[TITLE OF THE INVENTION] OPTICAL DISK DEVICE WITH FUNCTION FOR DETECTING SUBSTRATE THICKNESS ERROR

[WHAT IS CLAIMED IS;]

[Claim 1] An optical disk device for recording and reproducing information with respect to an image recording medium with a transparent substrate formed on a recording/reproducing surface by use of light, wherein

a thickness error of the transparent substrate is detected based on symmetry of a focus error signal and a peak-point deviation of a focus sum signal.

[Claim 2] The optical disk device according to Claim 1, wherein

a thickness error of the transparent substrate is detected by detecting a difference between an absolute value of a positive-side peak and an absolute value of a negative-side peak of a focus error signal obtained by use of a focus error signal detection system based on a knife-edge method.

[Claim 3] The optical disk device according to Claim 1, wherein

a thickness error of the transparent substrate is detected by detecting a difference in focus positions between a peak point of a focus sum signal and a zero point of a focus error signal obtained by use of a focus error signal detection system based on a knife-edge method.

[Claim 4] The optical disk device according to Claim 1, wherein

a thickness error of the transparent substrate is detected by detecting a difference between an absolute value of a positive-side peak and an absolute value of a negative-

side peak of a focus error signal obtained by use of a focus error signal detection system based on a spot-size method.

[Claim 5] The optical disk device according to Claim 1, wherein

a thickness error of the transparent substrate is detected by detecting a difference in focus positions between a peak point of a focus sum signal and a zero point of a focus error signal obtained by use of a focus error signal detection system based on a spot-size method.

[Claim 6] The optical disk device according to Claim 1, wherein

a thickness error of the transparent substrate is detected by comparing shapes between a waveform in the vicinity of a positive-side peak and a waveform in the vicinity of a negative-side peak of a focus error signal obtained by use of a focus error signal detection system based on an astigmatism method or by detecting an absolute amount of a focus pull-in range.

[Claim 7] The optical disk device according to Claim 1, wherein

a thickness error of the transparent substrate is detected by detecting a difference in focus positions between a peak point of a focus sum signal and a zero point of a focus error signal obtained by use of a focus error signal detection system based on an astigmatism method.

[Claim 8] The optical disk device according to any one of Claims 1 through 7, comprising a means for correcting spherical aberrations caused by a thickness error of the transparent substrate.

[Claim 9] The optical disk device according to Claim 8, wherein

when the information recording medium is newly loaded,

thickness errors of the transparent substrate are detected at a plurality of various radial positions of the information recording medium prior to performing a recording or reproducing operation to calculate correction factors for radial positions of the information recording medium, and during a subsequent recording or reproducing operation, spherical aberrations caused by a thickness error of the transparent substrate are corrected based on the correction factor.

[DETAILED DESCRIPTION OF THE INVENTION]

[Technical Field of the Invention]

The present invention relates to an optical disk device for recording and reproducing information by use of light, in particular, to an optical disk device capable of detecting a thickness error of a transparent substrate formed on an information recording medium.

[Prior Art]

Optical disks devices for recording and reproducing information by use of light, which are typical of CDs (compact disks) and DVDs (digital versatile disks), are widely used as information recording devices for images, sound, computer data and the like, and there has been an increasing demand for higher densities and larger capacities thereof in recent years. The recording density of an optical disk device can be effectively increased by reducing the spot diameters of light beams condensed on a recording/reproducing surface by means of increasing the NA (numerical aperture) of an objective lens mounted on an optical head that writes and reads information and shortening the wavelength of a light source.

Here, in an optical disk device or the like, since information recording and reproducing is usually carried out

by irradiating a recording/reproducing surface with light beams through a transparent substrate that serves as a protective layer, spherical aberrations occur if the thickness of the transparent substrate deviates from a specified value and this causes a degradation in recording/reproducing characteristics. Spherical aberrations due to a thickness error of the transparent substrate increase in proportion to the fourth power of the NA, and the level of an ordinary thickness error resulting from a disk molding process is permitted if the NA is on the order of 0.45 or 0.6 as in the prior art. However, this influence becomes critical when the NA is increased to achieve a higher density as described above, and a means for detecting a thickness error of the transparent substrate and correcting spherical aberrations resulting therefrom becomes necessary.

As examples of prior art methods for detecting a thickness error of a transparent substrate, there have been proposed methods, such as a method for detecting a thickness error of a transparent substrate based on a difference between respective focus error signals by condensing light on a recording surface and a transparent substrate surface using two light sources or an optical element for distributing a single light source to two light fluxes (Japanese Published Unexamined Patent Application No. 2000-11402 and Japanese Published Unexamined Application No. 2000-20993), and a method for detecting a thickness error or the like of a transparent substrate based on an intensity distribution obtained by overlaying light fluxes while spatially offsetting these using an optical element for splitting a light flux reflected from a recording surface through a transparent substrate (Japanese Published

Unexamined Application No. 2000-20999).

[Problems to be Solved by the Invention]

However, since all of the above-described prior art methods for detecting a thickness error of a transparent substrate require special optical systems for detecting thickness errors, this causes a decline in productivity and an increase in manufacturing costs due to the increasing numbers of parts and man-hours for adjustment as well as difficulty in designing smaller and lighter optical disk devices.

An object of the present invention is to provide an optical disk device which is capable of carrying out a stable high-density recording/reproduction without causing a substantial decline in productivity or increase in costs or increasing the device in size, by detecting a thickness error of a transparent substrate and correcting spherical aberrations resulting therefrom without the necessity for any special detection optical system regardless of an increase in the NA of an objective lens for a higher density.

[Means for Solving the Problems]

An optical disk device of the present invention is characterized by being capable of detecting a thickness error of a transparent substrate by use of a conventional focus error signal detection system according to a so-called knife-edge method, spot-size method, or astigmatism method without the necessity for any special detection optical system. That is, when the thickness of a transparent substrate deviates from a specified value, spherical aberrations occur, and beam expansions become asymmetrical before and after a detection plane to detect an information light reflected from a recording/reproduction surface, therefore, a focus error signal detected by use of a

conventional focus error signal detection system according to a so-called knife-edge method, spot-size method, or astigmatism method shows an asymmetrical curve which is different between the positive side and negative side according to the substrate thickness error amount. Moreover, since the light beams themselves condensed on the detection plane form a distorted diffraction image containing spherical aberrations, a focus sum signal, which is a sum of all detection lights obtained by the conventional focus error signal detection system, also changes relative to the substrate thickness error, and a peak point thereof has a difference from a zero point (focal point) of the focus error signal. According to the present invention, a thickness error of the transparent substrate is detected by utilizing such a difference in characteristics of a curve between the positive side and negative side of a focus error signal corresponding to the substrate thickness error amount and change in the peak point of a focus sum signal obtained by the conventional focus error signal detection system. Consequently, since no special optical system for detecting a thickness error of a transparent substrate is necessary, an optical disk device capable of carrying out a high-density recording/reproduction can be realized without causing a substantial decline in productivity or increase in costs or increasing the device in size.

[Embodiments of the Invention]

A first embodiment of the present invention is shown in Fig. 1. Fig. 1 shows an optical disk device for recording/reproducing information with respect to an information recording medium with a transparent substrate formed on a recording/reproducing surface by use of light, having a typical construction for detecting focus error

signals that detect deviations of condensing points of light beams condensing on the recording/reproducing surface by means of a so-called knife-edge method. Hereinafter, a principle of an optical disk device for detecting a thickness error of a transparent substrate using a focus error signal detection system based on a knife-edge method according to the present invention will be described by use of Fig. 1 and its auxiliary views Fig. 2 to Fig. 6.

First, description will be given of a construction of Fig. 1 and a principle of the focus error signal detection system based on a knife-edge method. A light beam released from a laser diode 1 penetrates through a polarizing beam splitter 2, becomes a parallel light by means of a collimator lens 3, enters an objective lens 6 via a spherical aberration corrector 5 and a quarter wavelength plate 4, passes through a transparent substrate 8 of an optical disk 7, and is condensed on a recording/reproducing surface by the objective lens 6. And, the light reflected on the recording/reproducing surface of the optical disk 7 passes through the transparent substrate 8 again, becomes a parallel light by means of the objective lens 6, is condensed by the collimator lens 3 via the quarter wavelength plate 4 and spherical aberration corrector 5, and enters the polarizing beam splitter 2. The light beam which has entered the polarizing beam splitter 2 is, since its plane of polarization has been rotated by 90º as a result of passing through the quarter wavelength plate 4 back and forth, reflected by the polarizing beam splitter 2, is diffracted by a hologram 9, and is irradiated on a light detector 11 via a detection lens 10. At this time, the detection lens 10 and light detector 11 have been located in such a manner that the light focuses on the light detector

11, when the recording/reproducing surface of the optical disk 7 is at a focus position of the light beam condensed by the objective lens 6. In addition, since patterns with different pitches have been formed in four sectors defined in the hologram 9, respectively, as shown in Fig. 2, light beams 12 diffracted by the hologram 9 are condensed on a light-receiving unit pattern 13 of the light detector 11, respectively, as shown in Fig. 3. Namely, among the light beams 12 which have entered the hologram 9, light beams of a ±1 order diffracted by a hologram pattern 9a are condensed on spots 12a and 12h formed on the light-receiving unit pattern 13 of the light detector 11, light beams of a ±1 order diffracted by a hologram pattern 9b are condensed on spots 12b and 12g, light beams of a ±1 order diffracted by a hologram pattern 9c are condensed on spots 12c and 12f, and light beams of a ±1 order diffracted by the hologram pattern 9d are condensed on spots 12d and 12e, respectively. And, when the recording/reproducing surface of the optical disk 7 approaches the objective lens 6, since the light beams to be irradiated on the light detector 11 are irradiated before these converge to focus, the light beams form spots 12a through 12h as shown in Fig. 4. To the contrary, when the recording/reproducing surface of the optical disk 7 moves away from the objective lens 6, the light beams to be irradiated on the light detector 11 are irradiated after these converge to focus before reaching the light detector 11, so that the light beams form spots 12a through 12h as shown in Fig. 5. Consequently, a focus error signal FE and a focus sum signal FS can be obtained by calculating output signals from light-receiving unit patterns 13a to 13d as in formula (1):

(1)

FE = (13a + 13d) - (13b + 13c)

FS = 13a + 13b + 13c + 13d

This is a typical focus error signal detection method, which is otherwise called a knife-edge method, and in the present embodiment, a focus error signal detection system according to this knife-edge method is used to detect a thickness error of a transparent substrate. Here, as the focus error signal detection system based on the knife-edge method to which the present invention is applied is not limited to the construction described above in Fig. 1, the present invention can be applied to any other detection systems based on this principle, such as a method where the light beam is split into two and only one thereof is used or a method using a Foucault prism as a means for splitting the beam, for example.

Next, description will be given of a principle of an optical disk device for detecting a thickness error of a transparent substrate using a focus error signal detection system based on a knife-edge method according to the present invention. In the focus error signal detection system based on the knife-edge method described in the foregoing, when a thickness of the transparent substrate has no deviation from a specified value, if the recording/reproducing surface of the optical disk 7 deviates forward or backward from a focal plane of the objective lens 6, spots irradiated on the light-receiving unit pattern 13 formed on the light detector 11 symmetrically enlarge, respectively, as shown in Fig. 3 to Fig. 5, and eventually expand beyond the light-receiving unit pattern 13. Therefore, a focus error signal 14 and a focus sum signal 15 as shown in Fig. 6 are obtained by calculating output signals from the light-receiving unit patterns 13a to 13d as in formula (1). Herein, since split

lines of the hologram 9 and split lines of the light-receiving unit pattern 13 have been positioned to be parallel with each other, an absolute value 16 of a positive-side peak of the focus error signal 14 of Fig. 6 is equal to an absolute value 17 of a negative-side peak. Moreover, a peak point 18 of the focus sum signal 15 coincides with a zero point 19 of the focus error signal 14 in focusing positions. However, when the thickness of the transparent substrate has a deviation from the specified value, since spherical aberrations resulting therefrom occur, if the recording/reproducing surface of the optical disk 7 deviates forward or backward from a focal plane of the objective lens 6, spots irradiated on the light-receiving unit pattern 13 formed on the light detector 11 asymmetrically enlarge as to whether the deviation is forward or backward from the same, and ones with a larger spot-enlarging ratio eventually expand beyond the light-receiving unit pattern 13 first. Therefore, provided is an asymmetrical S-curve where the absolute value 16 of the positive-side peak of the focus error signal 14 and the absolute value 17 of the negative-side peak are different. At this time, since the amount of spherical aberration to occur varies depending on the amount of the thickness error of the transparent substrate, the degree of an asymmetrical enlargement of the spots irradiated on the light-receiving unit pattern 13 formed on the light detector 11 varies as well, so that the difference to be obtained between the absolute value 16 of the positive-side peak and absolute value 17 of the negative-side peak of the focus error signal 14 changes depending on the amount of the thickness error of the transparent substrate. Moreover, since the polarity of spherical aberration to occur is different depending on

whether the thickness of the transparent substrate is thinner or thicker than the specified value, manners in which the asymmetrical enlargement occurs on the spots irradiated on the light-receiving unit pattern 13 formed on the light detector 11 are opposite in directions. Namely, the size relationship to be obtained between the absolute value 16 of the positive-side peak and the absolute value 17 of the negative-side peak of the focus error signal 14 is reversed depending on whether the thickness of the transparent substrate 8 is thinner or thicker than the specified value. Therefore, by comparing the absolute value 16 of the positive-side peak of the focus error signal 14 with the absolute value 17 of the negative-side peak in terms of the size relationship, the amount and direction of the thickness error of the transparent substrate can be detected. In addition, when spherical aberrations occur due to a thickness error of the transparent substrate, the spots themselves irradiated on the light-receiving unit pattern 13 formed on the light detector 11 develop distortions, and a blurred image accompanying side lobes is produced even in the vicinity of just-in-focus. Consequently, this develops a deviation in focusing positions between the peak point 18 of the focus sum signal 15 to detect a light amount of all spots and zero point 19 of the focus error signal 14 to reach a just-in-focus state. At this time, since the amount of spherical aberration to occur varies depending on the amount of the thickness error of the transparent substrate, the degree of distortions of the spots irradiated on the light-receiving unit pattern 13 formed on the light detector 11 varies as well, so that the difference in the focusing positions to be obtained between the peak point 18 of the focus sum signal 15 and zero point 19 of the focus error

signal 14 changes depending on the amount of the thickness error of the transparent substrate. Moreover, since the polarity of the occurred spherical aberration is different depending on whether the thickness of the transparent substrate is thinner or thicker than the specified value, the spots irradiated on the light-receiving unit pattern 13 formed on the light detector 11 show directly opposite changes before and after in the optical axis direction. Namely, the focusing position of the peak point 18 of the focus sum signal 15 relative to the zero point 19 of the focus error signal 14 is reversed depending on whether the thickness of the transparent substrate 8 is thinner or thicker than the specified value. Therefore, by detecting the difference in the focusing positions between the peak point 18 of the focus sum signal 15 and the zero point 19 of the focus error signal 14 including its sign, the absolute amount and direction of the thickness error of the transparent substrate can be detected.

Fig. 7 and Fig. 8 show simulation results of focus error signals and focus sum signals obtained when the thickness error of the transparent substrate is changed in a focus error signal detection system based on a knife-edge method. According to Fig. 7, when the thickness of the transparent substrate is thicker than the specified value, the absolute value of the negative-side peak becomes greater than the absolute value of the positive-side peak of a focus error signal according to the thickness error amount of the transparent substrate as mentioned above, so that the peak point of a focus sum signal relative to the zero point of the focus error signal deviates to the negative side. In addition, according to Fig. 8, when the thickness of the transparent substrate is thinner than the specified value,

the absolute value of the negative-side peak becomes smaller than the absolute value of the positive-side peak of a focus error signal according to the thickness error amount of the transparent substrate as mentioned above, so that the peak point of a focus sum signal relative to the zero point of the focus error signal deviates to the positive side. Therefore, the absolute amount and direction of the thickness error of the transparent substrate can be detected by detecting the difference between the absolute value of the positive-side peak and absolute value of the negative-side peak of the focus error signal or the difference between the peak point of the focus sum signal and zero point of the focus error signal.

By the method mentioned in the above, a signal processing unit 60 detects a thickness error amount of the transparent substrate, and a control unit 61 outputs a control signal to the spherical aberration corrector 5 so that the detected thickness error amount is minimized. As the spherical aberration corrector 5, a means for changing the wave surface within the optical system so as to cancel out spherical aberrations caused by a thickness error of the transparent substrate by use of a control signal (external drive signal) can be used, and for example, a method using a relay lens system or a liquid crystal element can be mentioned.

Since the optical disk device performs focusing and tracking control when performing a recording or reproducing operation, it is impossible to detect and correct a thickness error of the transparent substrate in real time during the recording or reproducing operation in the optical disk device of the present invention. However, when a new optical disk 7 is loaded, thickness errors of the

transparent substrate are detected at an equally spaced plurality of various radial positions prior to performing a recording or reproducing operation, and correction factors for radial positions of the optical disk 7 are calculated based on a plurality of detected signals of various radial positions, and during the subsequent recording or reproducing operation, spherical aberrations caused by the thickness error of the transparent substrate can be corrected based on this correction factor.

A second embodiment of the present invention is shown in Fig. 9. Fig. 9 shows an optical disk device for recording/reproducing information with respect to an information recording medium with a transparent substrate formed on a recording/reproducing surface by use of light, having a typical construction for detecting focus error signals that detect deviations of condensing points of light beams condensing on the recording/reproducing surface by means of a so-called spot-size method. Hereinafter, a principle of an optical disk device for detecting a thickness error of a transparent substrate using a focus error signal detection system based on a spot-size method according to the present invention will be described by use of Fig. 9 and its auxiliary views Fig. 10 to Fig. 13.

First, description will be given of a construction of Fig. 9 and a principle of the focus error signal detection system based on a spot-size method. A light beam released from a laser diode 20 penetrates through a polarizing beam splitter 21, becomes a parallel light by means of a collimator lens 22, enters an objective lens 25 via a spherical aberration corrector 24 and a quarter wavelength plate 23, passes through a transparent substrate 27 of an optical disk 26, and is condensed on a recording/reproducing

surface by the objective lens 25. And, the light reflected on the recording/reproducing surface of the optical disk 26 passes through the transparent substrate 27 again, becomes a parallel light by means of the objective lens 25, is condensed by the collimator lens 22 via the quarter wavelength plate 23 and spherical aberration corrector 24, and enters the polarizing beam splitter 21. The light beam which has entered the polarizing beam splitter 21 is, since its plane of polarization has been rotated by 90º as a result of passing through the quarter wavelength plate 23 back and forth, reflected by the polarizing beam splitter 21, and a 50% thereof is reflected by a half mirror 29 via a detection lens 28, a remaining 50% penetrates, and these are irradiated on a light detector 30 and a light detector 31, respectively. At this time, the light detector 30 and light detector 31 have been located in such a manner that these are equally distanced in the optical axis direction from, ahead and behind of, a focus position of the light beam condensed by the detection lens 28, when the recording/reproducing surface of the optical disk 26 is at a focus position of the light beam condensed by the objective lens 25, therefore, as shown in Fig. 10, identical spots 34 and 35 are formed on light-receiving unit patterns 32 and 33 formed on the optical detector 30 and optical detector 31, respectively. And, when the recording/reproducing surface of the optical disk 26 approaches the objective lens 25, since focus positions of the light beams irradiated on the light detector 30 and light detector 31 deviate backward, the spot 34 to be formed on a light-receiving unit pattern 32 on the light detector 30 enlarges, while the spot 35 to be formed on a light-receiving unit pattern 33 on the light detector 31 contracts as shown in Fig. 11. To the contrary,

when the recording/reproducing surface of the optical disk 26 moves away from the objective lens 25, since focus positions of the light beams irradiated on the light detector 30 and light detector 31 deviate forward, the spot 34 to be formed on a light-receiving unit pattern 32 on the light detector 30 contracts, while the spot 35 to be formed on a light-receiving unit pattern 33 on the light detector 31 enlarges as shown in Fig. 12. Consequently, a focus error signal FE and a focus sum signal FS can be obtained by calculating output signals from light-receiving unit patterns 32a to 32c and light-receiving unit patterns 33a to 33c as in formula (2):

(2)

$$FE = \{(32a + 32c) - 32b\} - \{(33a + 33c) - 33b\}$$

$$FS = 32a + 32b + 32c + 33a + 33b + 33c$$

This is a typical focus error signal detection method, which is otherwise called a spot-size method, and in the present embodiment, a focus error signal detection system according to this spot-size method is used to detect a thickness error of a transparent substrate. Here, as the focus error signal detection system based on the spot-size method to which the present invention is applied is not limited to the construction described above in Fig. 9, the present invention can be applied to any other detection systems based on this principle, such as a method using a hologram or the like with lens power as a means for splitting the beam, for example.

Next, description will be given of a principle of an optical disk device for detecting a thickness error of a transparent substrate using a focus error signal detection system based on a spot-size method according to the present invention. In the focus error signal detection system based

on the spot-size method described in the foregoing, when a thickness of the transparent substrate has no deviation from a specified value, if the recording/reproducing surface of the optical disk 26 deviates forward or backward from a focal plane of the objective lens 25, the spot 34 and spot 35 irradiated on the light-receiving unit pattern 32 and light-receiving unit pattern 33 formed on the light detector 30 and light detector 31 enlarge or contract at an identical ratio, respectively, as shown in Fig. 10 to Fig. 12, and the enlarged spot eventually expands beyond the light-receiving unit pattern 32 or light-receiving unit pattern 33. Therefore, a focus error signal 36 and a focus sum signal 37 as shown in Fig. 13 are obtained by calculating output signals from the light-receiving unit patterns 32a to 32c and light-receiving unit patterns 33a to 33c as in formula (2). Herein, since the light beams to be irradiated on the light detector 30 and light detector 31 have been positioned so that spots are formed at centers of the light-receiving unit pattern 32 and light-receiving unit pattern 33, an absolute value 38 of a positive-side peak of the focus error signal 36 of Fig. 13 is equal to an absolute value 39 of a negative-side peak. Moreover, a peak point 40 of the focus sum signal 37 coincides with a zero point 41 of the focus error signal 36 in focusing positions. However, when the thickness of the transparent substrate has a deviation from the specified value, since spherical aberrations resulting therefrom occur, if the recording/reproducing surface of the optical disk 26 deviates forward or backward from a focal plane of the objective lens 25, spots irradiated on the light-receiving unit pattern 32 and light-receiving unit pattern 33 formed on the light detector 30 and light detector 31 asymmetrically enlarge or contract as to whether

the deviation is forward or backward from the same, respectively, and ones with a larger spot-enlarging ratio eventually expand beyond the light-receiving unit pattern 32 or light-receiving unit pattern 33 first. Therefore, provided is an asymmetrical S-curve where the absolute value 38 of the positive-side peak of the focus error signal 36 and the absolute value 39 of the negative-side peak are different. At this time, since the amount of spherical aberration to occur varies depending on the amount of the thickness error of the transparent substrate, the degree of an asymmetrical enlargement or contraction of the spots irradiated on the light-receiving unit pattern 32 and light-receiving unit pattern 33 formed on the light detector 30 and light detector 31 varies as well, so that the difference to be obtained between the absolute value 38 of the positive-side peak and absolute value 39 of the negative-side peak of the focus error signal 36 changes depending on the amount of the thickness error of the transparent substrate. Moreover, since the polarity of spherical aberration to occur is different depending on whether the thickness of the transparent substrate is thinner or thicker than the specified value, manners in which the asymmetrical enlargement or contraction occurs on the spots irradiated on the light-receiving unit pattern 32 and light-receiving unit pattern 33 formed on the light detector 30 and light detector 31 are opposite in directions. Namely, the size relationship to be obtained between the absolute value 38 of the positive-side peak and the absolute value 39 of negative-side peak of the focus error signal 36 is reversed depending on whether the thickness of the transparent substrate is thinner or thicker than the specified value. Therefore, by comparing the absolute value 38 of the

positive-side peak of the focus error signal 36 with the absolute value 39 of the negative-side peak in terms of the size relationship, the absolute amount and direction of the thickness error of the transparent substrate can be detected. In addition, when spherical aberrations occur due to a thickness error of the transparent substrate, the spots themselves irradiated on the light-receiving unit pattern 32 and light-receiving unit pattern 33 formed on the light detector 30 and light detector 31 develop distortions, and a blurred image accompanying side lobes is produced even in the vicinity of just-in-focus. Consequently, this develops a deviation in focusing positions between the peak point 40 of the focus sum signal 37 to detect a light amount of all spots and zero point 41 of the focus error signal 36 to reach a just-in-focus state. At this time, since the amount of spherical aberration to occur varies depending on the amount of the thickness error of the transparent substrate, the degree of distortions of the spots irradiated on the light-receiving unit pattern 32 and light-receiving unit pattern 33 formed on the light detector 30 and light detector 31 varies as well, so that the difference in the focusing positions to be obtained between the peak point 40 of the focus sum signal 37 and zero point 41 of the focus error signal 36 changes depending on the amount of the thickness error of the transparent substrate. Moreover, since the polarity of the occurred spherical aberration is different depending on whether the thickness of the transparent substrate is thinner or thicker than the specified value, the spots irradiated on the light-receiving unit pattern 32 and light-receiving unit pattern 33 formed on the light detector 30 and light detector 31 show directly opposite changes before and after in the optical axis

direction. Namely, the focusing position of the peak point 40 of the focus sum signal 37 relative to the zero point 41 of the focus error signal 36 is reversed depending on whether the thickness of the transparent substrate is thinner or thicker than the specified value. Therefore, by detecting the difference in the focusing positions between the peak point 40 of the focus sum signal 37 and the zero point 41 of the focus error signal 36 including its sign, the absolute amount and direction of the thickness error of the transparent substrate can be detected.

Fig. 14 and Fig. 15 show simulation results of focus error signals and focus sum signals obtained when the thickness error of the transparent substrate is changed in a focus error signal detection system based on a spot-size method. According to Fig. 14, when the thickness of the transparent substrate is thicker than the specified value, the absolute value of the negative-side peak becomes greater than the absolute value of the positive-side peak of a focus error signal according to the thickness error amount of the transparent substrate as mentioned above, so that the peak point of a focus sum signal relative to the zero point of the focus error signal deviates to the negative side. In addition, according to Fig. 15, when the thickness of the transparent substrate is thinner than the specified value, the absolute value of the negative-side peak becomes smaller than the absolute value of the positive-side peak of a focus error signal according to the thickness error amount of the transparent substrate as mentioned above, so that the peak point of a focus sum signal relative to the zero point of the focus error signal deviates to the positive side. Therefore, the absolute amount and direction of the thickness error of the transparent substrate can be detected

by detecting the difference between the absolute value of the positive-side peak and absolute value of the negative-side peak of the focus error signal or the difference between the peak point of the focus sum signal and zero point of the focus error signal. Then, spherical aberrations caused by the thickness error of the transparent substrate detected via a signal processing unit 60 and a control unit 61 are corrected by means of the spherical aberration corrector 24 as described above in the first embodiment, whereby it becomes possible to carry out a stable high-density recording/reproduction.

A third embodiment of the present invention is shown in Fig. 16. Fig. 16 shows an optical disk device for recording/reproducing information with respect to an information recording medium with a transparent substrate formed on a recording/reproducing surface by use of light, having a typical construction for detecting focus error signals that detect deviations of condensing points of light beams condensing on the recording/reproducing surface by means of a so-called astigmatism method. Hereinafter, a principle of an optical disk device for detecting a thickness error of a transparent substrate using a focus error signal detection system based on an astigmatism method according to the present invention will be described by use of Fig. 16 and its auxiliary views Fig. 17 to Fig. 20.

First, description will be given of a construction of Fig. 16 and a principle of the focus error signal detection system based on an astigmatism method. A light beam released from a laser diode 42 penetrates through a polarizing beam splitter 43, becomes a parallel light by means of a collimator lens 44, enters an objective lens 47 via a spherical aberration corrector 46 and a quarter

wavelength plate 45, passes through a transparent substrate 49 of an optical disk 48, and is condensed on a recording/reproducing surface by the objective lens 47. And, the light reflected on the recording/reproducing surface of the optical disk 48 passes through the transparent substrate 49 again, becomes a parallel light by means of the objective lens 47, is condensed by the collimator lens 44 via the quarter wavelength plate 45 and spherical aberration corrector 46, and enters the polarizing beam splitter 43. The light beam which has entered the polarizing beam splitter 43 is, since its plane of polarization has been rotated by 90º as a result of passing through the quarter wavelength plate 45 back and forth, reflected by the polarizing beam splitter 43, and is irradiated on a light detector 52 via a detection lens 50 and a cylindrical lens 51 that serves as an astigmatism generating means. At this time, the generatrix (direction without lens power) of the cylindrical lens 51 that serves as an astigmatism generating means has been arranged so as to create 45º against the direction of a split line of a light-receiving unit pattern 53, which has been formed on the light detector 52 and split into four sectors, and the light detector 52 has been positioned in such a manner that this will be at the position of a circle of least confusion due to astigmatism generated by the cylindrical lens 51, when the recording/reproducing surface of the optical disk 48 is at a focus position of the light beam condensed by the objective lens 47. Therefore, the light beam irradiated on the light-receiving unit pattern 53 formed on the light detector 52 forms a circular spot 54 as shown in Fig. 17 when the recording/reproducing surface of the optical disk 48 is located at the focus position of the light beam

condensed by the objective lens 47, however, when the recording/reproducing surface of the optical disk 7 approaches or moves away with respect to the objective lens 47, the light beam forms elliptical spots 54, which extend in directions perpendicular to each other as shown in Fig. 18 and Fig. 19. Consequently, a focus error signal FE and a focus sum signal FS can be obtained by calculating output signals from light-receiving unit patterns 53a to 53d as in formula (3):

$$FE = (53a + 53d) - (53b + 53c)$$

$$FS = 53a + 53b + 53c + 53d$$

This is a typical focus error signal detection method, which is otherwise called an astigmatism method, and in the present embodiment, a focus error signal detection system according to this astigmatism method is used to detect a thickness error of a transparent substrate. Here, as the focus error signal detection system based on the astigmatism method to which the present invention is applied is not limited to the construction described above in Fig. 16, the present invention can be applied to any other detection systems based on this principle, such as a method arranging a parallel flat plate with a tilt in the optical axis direction as an astigmatism generating means, for example.

Next, description will be given of a principle of an optical disk device for detecting a thickness error of a transparent substrate using a focus error signal detection system based on an astigmatism method according to the present invention. In the focus error signal detection system based on the astigmatism method described in the foregoing, when a thickness of the transparent substrate has no deviation from a specified value, if the recording/reproducing surface of the optical disk 48

deviates forward or backward from a focal plane of the objective lens 47, spots 54 irradiated on the light-receiving unit pattern 53 formed on the light detector 52 enlarge in elliptical forms almost symmetrically in directions perpendicular to each other, respectively, as shown in Fig. 17 to Fig. 19, and eventually expand beyond the light-receiving unit pattern 53. Therefore, a focus error signal 55 and focus sum signal 56 as shown in Fig. 20 are obtained by calculating output signals from light-receiving unit patterns 53a to 53d as in formula (3). At this time, provided is a symmetrical S-curve where a shape in the vicinity 57 of a positive-side peak of the focus error signal 55 and a shape in the vicinity 58 of a negative-side peak are almost equal. Moreover, a peak point 60 of the focus sum signal 56 coincides with a zero point 61 of the focus error signal 55 in focusing positions. However, when the thickness of the transparent substrate has a deviation from the specified value, since spherical aberrations resulting therefrom occur, if the recording/reproducing surface of the optical disk 48 deviates forward or backward from a focal plane of the objective lens 47, spots 54 irradiated on the light-receiving unit pattern 53 formed on the light detector 52 enlarge into asymmetrical elliptical forms in different shapes, respectively, with either thereof having a light distribution in such a shape where end parts in the short axis direction or long axis direction of the ellipse are expanded. Therefore, provided is an asymmetrical S-curve where a shape in the vicinity 57 of a positive-side peak of the focus error signal 55 and a shape in the vicinity 58 of a negative-side peak are different, and a focus pull-in range 59, which is a distance between the peaks, enlarges.

At this time, since the amount of spherical aberration to occur varies depending on the amount of the thickness error of the transparent substrate, the degree of an asymmetrical enlargement of the spot 54 irradiated on the light-receiving unit pattern 53 formed on the light detector 52 varies as well, so that the focus pull-in range 59 of the focus error signal 55 to be obtained changes depending on the amount of the thickness error of the transparent substrate. Moreover, a waveform of either the vicinity 57 of the positive-side peak of the focus error signal 55 or vicinity 58 of the negative-side peak has a dull shape, however, since the polarity of spherical aberration to occur is different depending on whether the thickness of the transparent substrate is thinner or thicker than the specified value, manners in which the asymmetrical enlargement occurs on the spots 54 irradiated on the light-receiving unit pattern 53 formed on the light detector 52 are opposite in directions, so that the side where the waveform in the vicinity of the peak of the focus error signal 55 has a dull shape is different depending on whether the thickness of the transparent substrate is thinner or thicker than the specified value. Therefore, by comparing an absolute value of the focus pull-in range 59 of the focus error signal 55 with a waveform shape in the vicinity of the peak, the absolute amount and direction of the thickness error of the transparent substrate can be detected. In addition, when spherical aberrations occur due to a thickness error of the transparent substrate, the spots themselves irradiated on the light-receiving unit pattern 53 formed on the light detector 52 develop distortions, and a blurred image accompanying side lobes is produced even in the vicinity of just-in-focus. Consequently, this develops a deviation in

focusing positions between the peak point 60 of the focus sum signal 56 to detect a light amount of all spots and zero point 61 of the focus error signal 55 to reach a just-in-focus state. At this time, since the amount of spherical aberration to occur varies depending on the amount of the thickness error of the transparent substrate, the degree of distortions of the spots 54 irradiated on the light-receiving unit pattern 53 formed on the light detector 52 varies as well, so that the difference in the focusing positions to be obtained between the peak point 60 of the focus sum signal 56 and zero point 61 of the focus error signal 55 changes depending on the amount of the thickness error of the transparent substrate. Moreover, since the polarity of the occurred spherical aberration is different depending on whether the thickness of the transparent substrate is thinner or thicker than the specified value, the spots 54 irradiated on the light-receiving unit pattern 53 formed on the 52 show directly opposite changes before and after in the optical axis direction. Namely, the focusing position of the peak point 60 of the focus sum signal 56 relative to the zero point 61 of the focus error signal 55 is reversed depending on whether the thickness of the transparent substrate is thinner or thicker than the specified value. Therefore, by detecting the difference in the focusing positions between the peak point 60 of the focus sum signal 56 and the zero point 61 of the focus error signal 55 including its sign, the absolute amount and direction of the thickness error of the transparent substrate can be detected.

Fig. 21 and Fig. 22 show simulation results of focus error signals and focus sum signals obtained when the thickness error of the transparent substrate is changed in a

focus error signal detection system based on an astigmatism method. According to Fig. 21, when the thickness of the transparent substrate is thicker than the specified value, the waveform in the vicinity of the negative-side peak becomes a duller shape than that in the vicinity of the positive-side peak of a focus error signal as mentioned above, so that the focus pull-in range enlarges according to the thickness error amount of the transparent substrate. In addition, the peak point of a focus sum signal relative to the zero point of the focus error signal deviates to the negative side. According to Fig. 22, when the thickness of the transparent substrate is thinner than the specified value, the waveform in the vicinity of the positive-side peak becomes a duller shape than that in the vicinity of the negative-side peak of a focus error signal as mentioned above, so that the focus pull-in range enlarges according to the thickness error amount of the transparent substrate. In addition, the peak point of a focus sum signal relative to the zero point of the focus error signal deviates to the positive side. Therefore, the absolute amount and direction of the thickness error of the transparent substrate can be detected by comparing shapes between the waveform in the vicinity of the positive-side peak of the focus error signal and waveform in the vicinity of the negative-side peak and detecting an absolute amount of the focus pull-in range, or detecting a difference between the peak point of the focus sum signal and zero point of the focus error signal.

[Effects of the Invention]

As has been described above, according to the present invention, even when it is necessary to detect and correct a thickness error of a transparent substrate as a result of an increase in the NA of an objective lens for a higher density,

a thickness error of a transparent substrate can be detected by use of a conventional focus error signal detection system according to a so-called knife-edge method, spot-size method, or astigmatism method without the necessity for any special detection optical system. Thereby, an optical disk device capable of carrying out a high-density recording/reproduction can be realized without causing a substantial decline in productivity or increase in costs or increasing the device in size.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1] A block diagram showing a first embodiment of the present invention.

[Fig. 2] A pattern diagram of a hologram element used in the first embodiment of the present invention.

[Fig. 3] A pattern diagram of a light-receiving unit of a light detector used in the first embodiment of the present invention and a diagram showing the shape of spots formed on the light detector when an optical disk is on an in-focus point.

[Fig. 4] A pattern diagram of a light-receiving unit of a light detector used in the first embodiment of the present invention and a diagram showing the shape of spots formed on the light detector when the optical disk is closer than the in-focus point.

[Fig. 5] A pattern diagram of the light-receiving unit of a light detector used in the first embodiment of the present invention and a diagram showing the shape of spots formed on the light detector when the optical disk is further than the in-focus point.

[Fig. 6] A diagram showing a focus error signal and a focus sum signal obtained in the first embodiment of the present invention.

[Fig. 7] to [Fig. 8] Diagrams showing simulation results of a focus error signal and a focus sum signal obtained by using a focus error signal detection system based on a knife-edge method in the first embodiment of the present invention.

[Fig. 9] A block diagram showing a second embodiment of the present invention.

[Fig. 10] A pattern diagram of a light-receiving unit of a light detector used in the second embodiment of the present invention and a diagram showing the shape of spots formed on the light detector when an optical disk is on an in-focus point.

[Fig. 11] A pattern diagram of a light-receiving unit of a light detector used in the second embodiment of the present invention and a diagram showing the shape of spots formed on the light detector when the optical disk is closer than the in-focus point.

[Fig. 12] A pattern diagram of the light-receiving unit of a light detector used in the second embodiment of the present invention and a diagram showing the shape of spots formed on the light detector when the optical disk is further than the in-focus point.

[Fig. 13] A diagram showing a focus error signal and a focus sum signal obtained in the second embodiment of the present invention.

[Fig. 14] to [Fig. 15] Diagrams showing simulation results of a focus error signal and a focus sum signal obtained by using a focus error signal detection system based on a spot-size method in the second embodiment of the present invention.

[Fig. 16] A block diagram showing a third embodiment of the present invention.

[Fig. 17] A pattern diagram of a light-receiving unit of a light detector used in the third embodiment of the present invention and a diagram showing the shape of spots formed on the light detector when an optical disk is on an in-focus point.

[Fig. 18] A pattern diagram of a light-receiving unit of a light detector used in the third embodiment of the present invention and a diagram showing the shape of spots formed on the light detector when the optical disk is closer than the in-focus point.

[Fig. 19] A pattern diagram of a light-receiving unit of a light detector used in the third embodiment of the present invention and a diagram showing the shape of spots formed on the light detector when the optical disk is further than the in-focus point.

[Fig. 20] A diagram showing a focus error signal and a focus sum signal obtained in the third embodiment of the present invention.

[Fig. 21] to [Fig. 22] Diagrams showing simulation results of a focus error signal and a focus sum signal obtained by using a focus error signal detection system based on an astigmatism method in the third embodiment of the present invention.

[Description of Symbols]

1, 20, 42 Laser diode

2, 21, 43 Polarizing beam splitter

3, 22, 44 Collimator lens

4, 23, 45 Quarter wavelength plate

5, 24, 46 Spherical aberration corrector

6, 25, 47 Objective lens

7, 26, 48 Optical disk

8, 27, 49 Transparent substrate

9 Hologram

9a-9d Hologram patterns

10, 28, 50 Detection lens

11, 30, 31, 52 Light detector

13, 13a-13h, 32, 32a-32c, 33, 33a-33c, 53, 53a-53d Light-receiving unit pattern

12 Light beam

12a-12h, 34, 35, 54 Spot

14, 36, 55 Focus error signal

15, 37, 56 Focus sum signal

16, 38 Absolute value of the positive-side peak of focus error signal

17, 39 Absolute value of the negative-side peak of focus error signal

18, 40, 60 Peak point of focus sum signal

19, 41, 60 Zero point of the focus error signal

29 Half mirror

51 Cylindrical lens

57 Vicinity of the positive-side peak of focus error signal

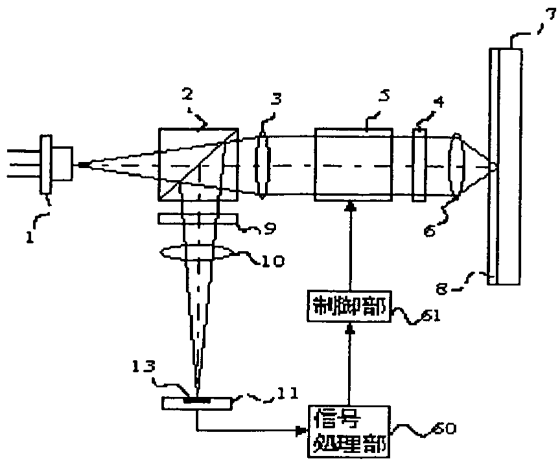
58 Vicinity of the negative-side peak of focus error signal

59 Focus pull-in range

60 Signal processing unit

61 Control unit

【図1】



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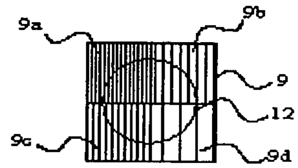

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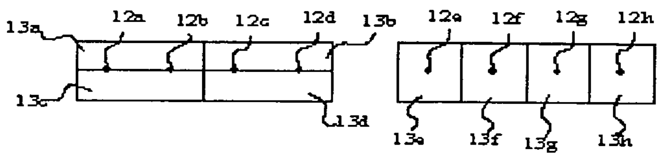

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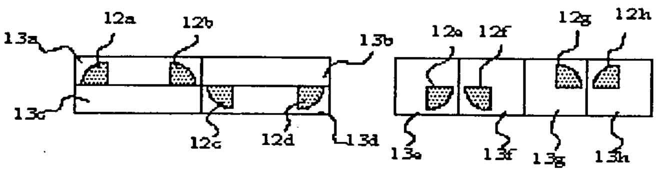

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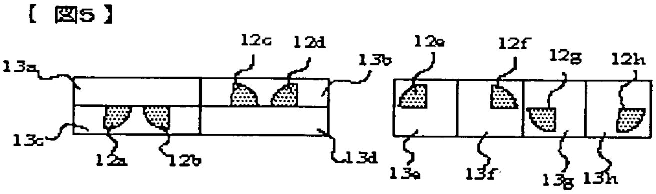

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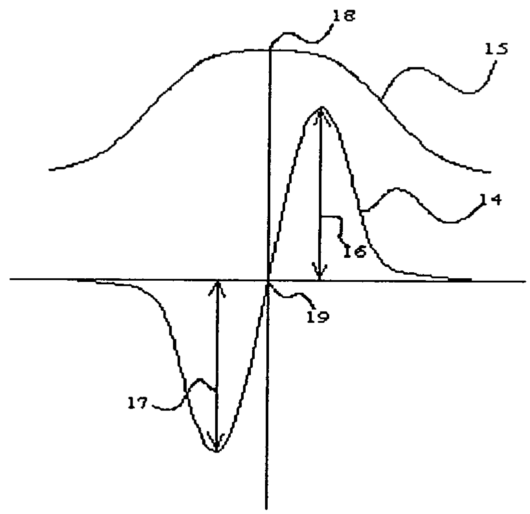

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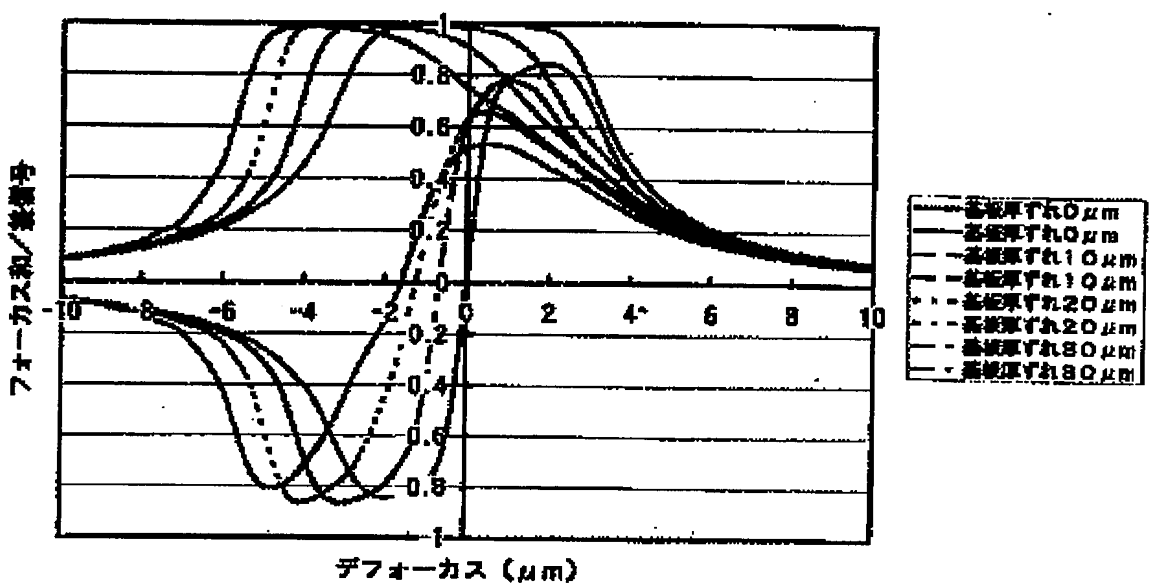

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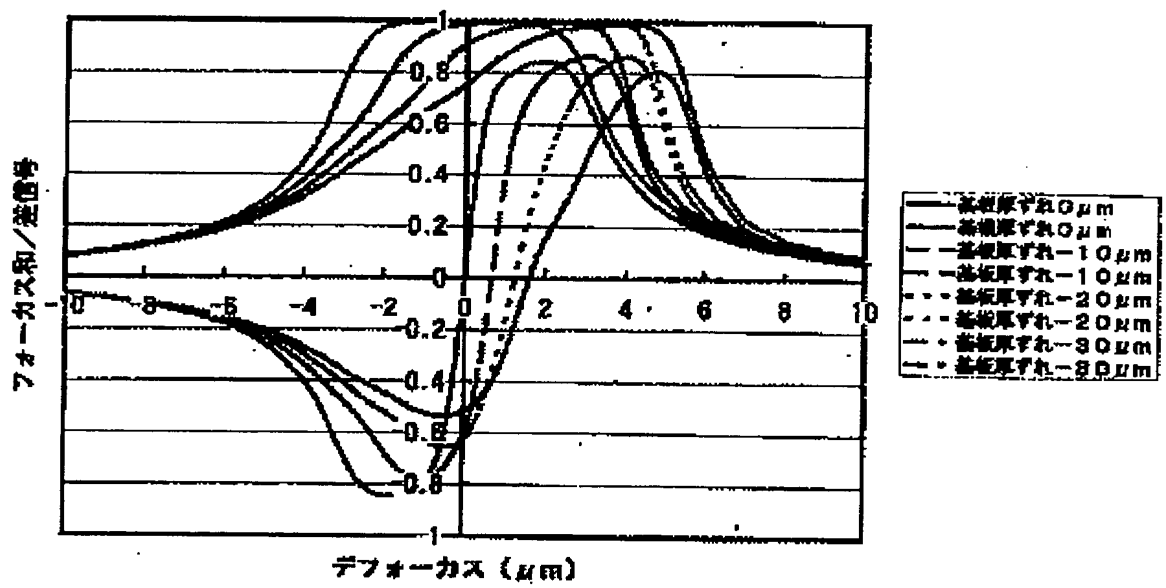

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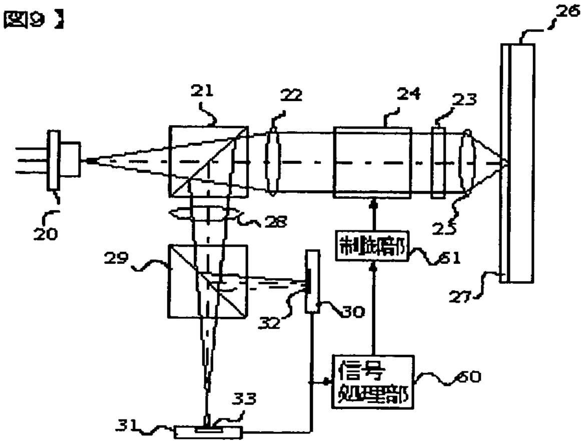

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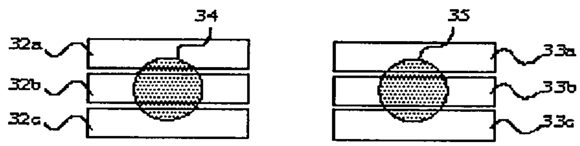

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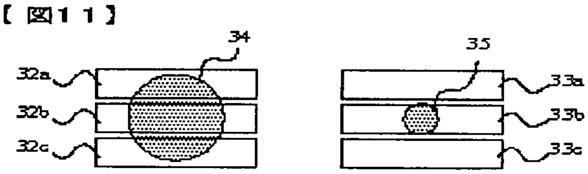

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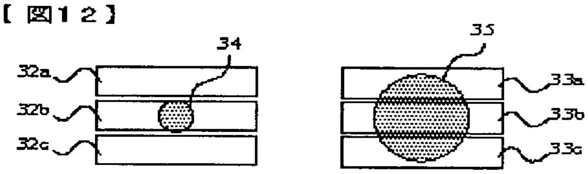

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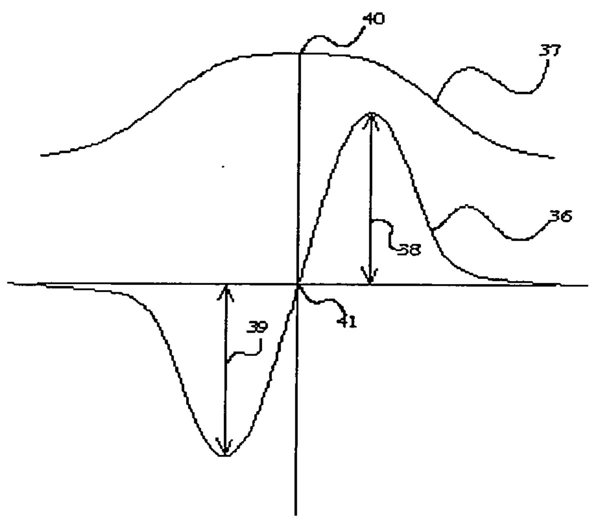

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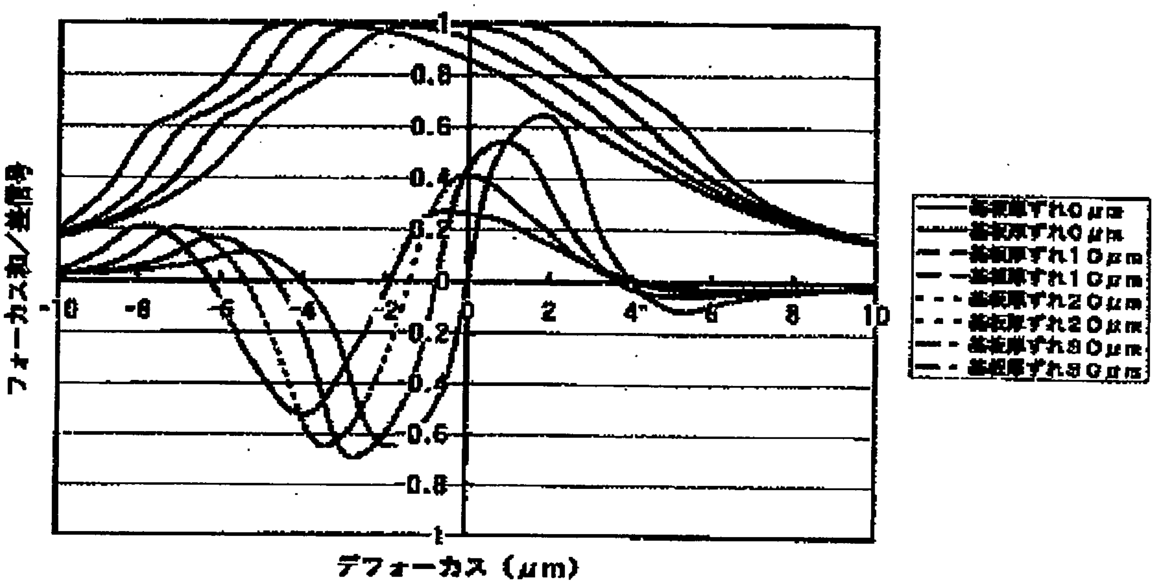
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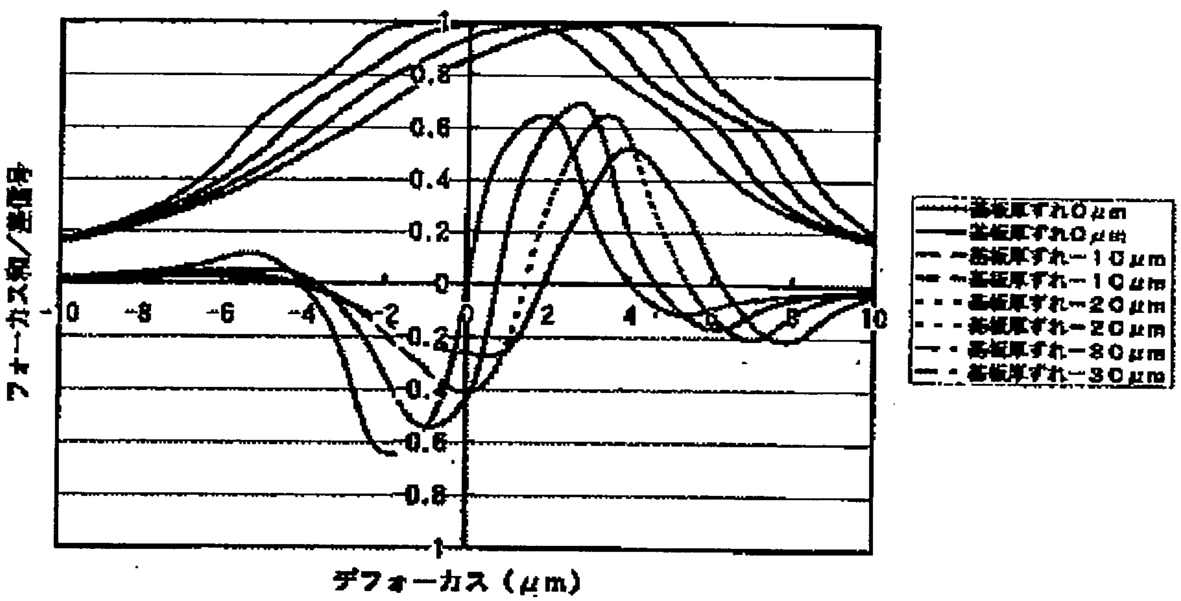
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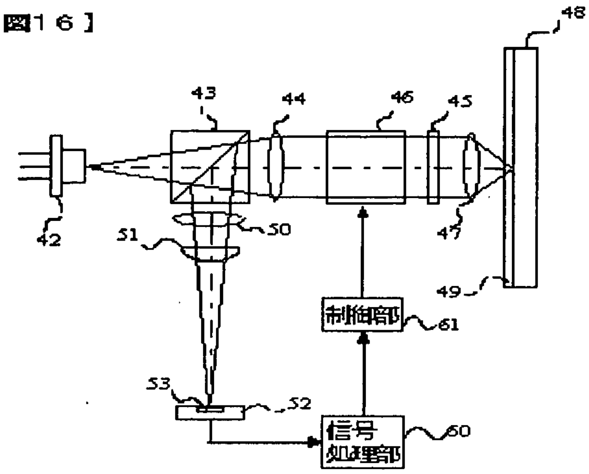

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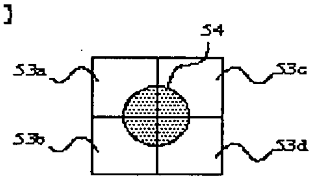

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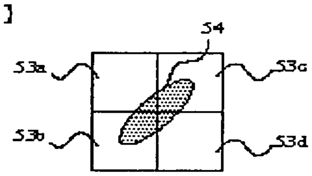

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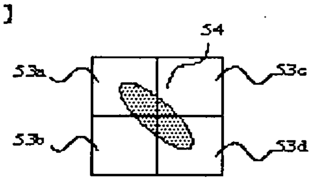

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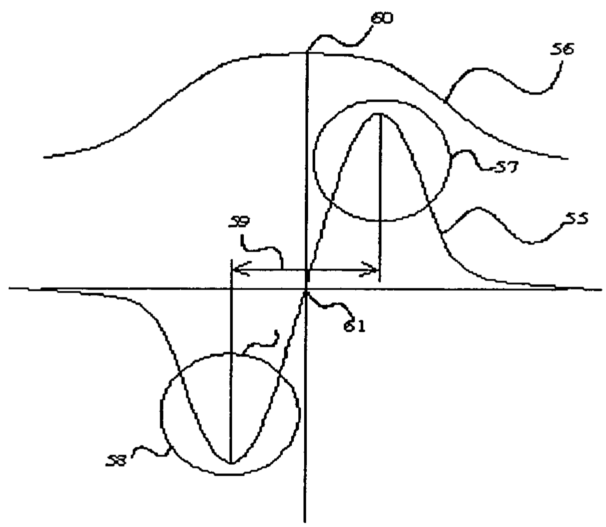

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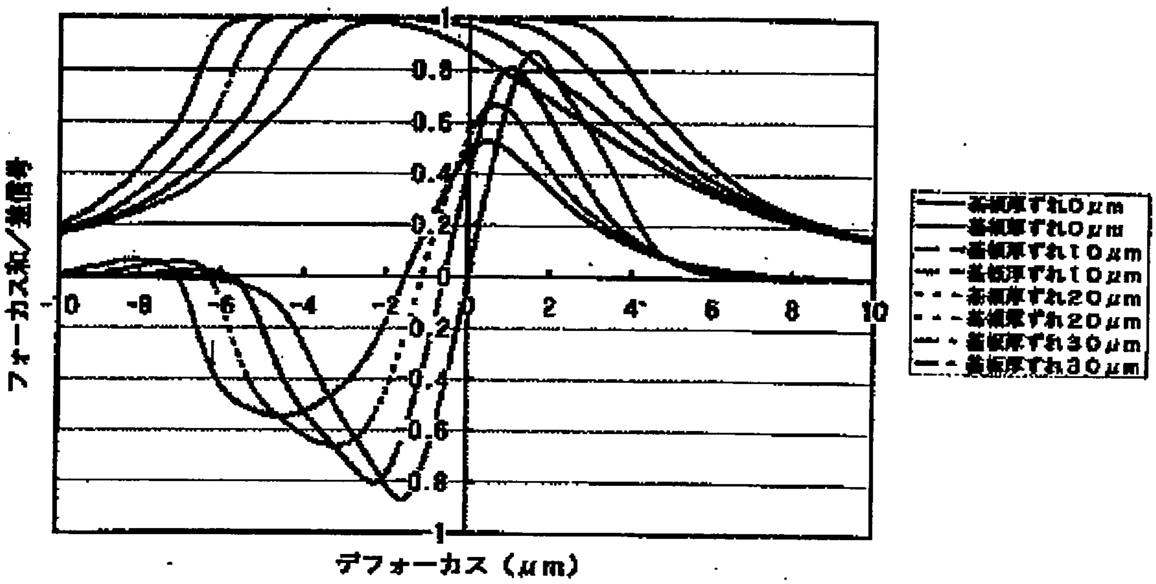

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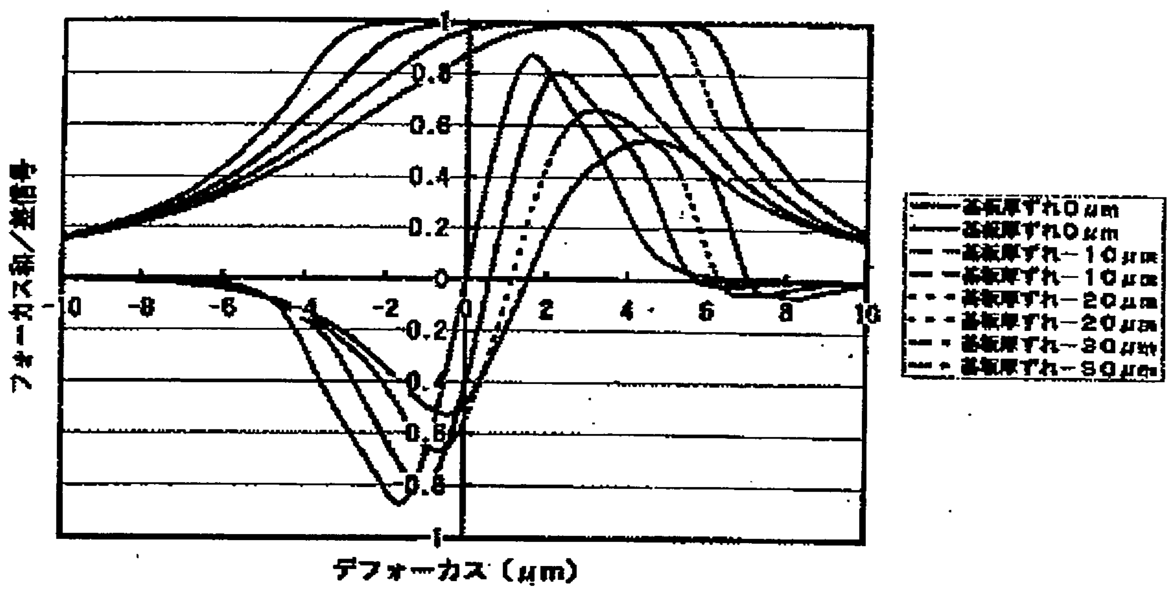

【書類名】　要約書

【要約】

【課題】

記録再生面上に透明基板が形成されている情報記録媒体の透明基板の厚み誤差を、特別な検出光学系を必要とせずに従来のフォーカス誤差信号検出系を用いて検出することが可能な光ディスク装置を提供する。

【解決手段】

情報記録媒体からの反射光が透明基板の厚み誤差に伴って生じる球面収差により、検出面での回折像の歪や検出面前後で非対称に拡大することを利用して、従来の一般的なフォーカス誤差信号検出系を用いて透明基板の厚み誤差を検出する。例えば、ナイフエッジ法によるフォーカス誤差信号検出系を用いて、得られるフォーカス誤差信号１４の＋側ピークの絶対値１６と－側ピークの絶対値１７の差、あるいはフォーカス和信号１５のピーク点

[TITLE OF DOCUMENT] Abstract

[ABSTRACT]

[OBJECT]

To provide an optical disk device which can detect a thickness error of a transparent substrate of an information recording medium with a transparent substrate formed on a recording/reproducing surface by use of a conventional focus error signal detection system without the necessity for a special detection optical system.

[SOLUTION MEANS]

A thickness error of a transparent substrate is detected by use of a conventional general focus error signal detection system by employing the fact that a light reflected from an information recording medium causes distortions in a diffraction image at a detection plane or asymmetrical enlargements before and after the detection plane due to spherical aberrations as a result of a thickness error of the transparent substrate. The absolute amount and direction of a thickness error of the transparent substrate can be detected by detecting a difference between an absolute value 16 of a positive-side peak and an absolute value 17 of a negative side peak of a focus error signal 14 or a difference in focus positions between a peak point 18 of a focus sum signal 15 and a zero point 19 of the focus error signal obtained by use of a focus error signal detection system based on a knife-

edge method, for example.

[SELECTED DRAWING] Fig. 6